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Next-to-leading order QCD corrections to single-inclusive hadron production in transversely polarized pp and p̄p collisions

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We present a calculation of the next-to-leading order QCD corrections to the partonic cross sections contributing to single-inclusive high-p_T hadron production in collisions of transversely polarized hadrons. We use a recently developed projection technique for treating the phase space integrals in the presence of the $\cos(2\Phi)$ azimuthal-angular dependence associated with transverse polarization. Our phenomenological results show that the double-spin asymmetry $A_{\rm TT}^{\pi}$ for neutral-pion production is expected to be very small for polarized pp scattering at RHIC and could be much larger for the proposed experiments with an asymmetric $\bar{p}p$ collider at the GSI.

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I. INTRODUCTION

The partonic structure of spin-1/2 targets at the leading-twist level is characterized entirely by the unpolarized, longitudinally polarized, and transversely polarized distribution functions f, Δf, and δf, respectively [1]. Of these, the "transversity" distributions δf remain virtually unknown. They are defined [1–4] as the differences of probabilities for finding a parton of flavor f at scale μ and light-cone momentum fraction x with its spin aligned ($\uparrow\uparrow$) or anti-aligned ($\downarrow\uparrow$) with that of the transversely polarized nucleon:

$$\delta f(x,\mu) \equiv f_{\uparrow\uparrow}(x,\mu) - f_{\downarrow\uparrow}(x,\mu) \; . \tag{1}$$

A program of polarized pp collisions is now underway at the BNL Relativistic Heavy Ion Collider (RHIC) [5], aiming at further unraveling the spin structure of the proton. Collisions of transversely polarized protons are hoped to give information on transversity through, e.g., the measurement of double-spin asymmetries

$$A_{\rm TT} = \frac{\frac{1}{2}\left[d\sigma(\uparrow\uparrow) - d\sigma(\uparrow\downarrow)\right]}{\frac{1}{2}\left[d\sigma(\uparrow\uparrow) + d\sigma(\uparrow\downarrow)\right]} \equiv \frac{d\delta\sigma}{d\sigma} \tag{2}$$

for various reactions with observed produced high-transverse momentum (p_T) or invariant mass. The best-studied, and perhaps most promising among these, is the Drell-Yan process [2, 6, 7], which offers the largest spin asymmetries but whose main drawback is the rather moderate event rate. Other reactions, such as high-p_T prompt-photon, pion, or jet production, are much more copious, but suffer from fairly small spin asymmetries [3, 8–11], due to large contributions from gluon-gluon and quark-gluon scattering only present in the unpolarized cross section in the denominator of Eq. (2).

Very recently, it has also been proposed to extract transversity from measurements of $A_{\rm TT}$ in transversely polarized $\bar{p}p$ collisions at the planned GSI-FAIR facility [12–14] near Darmstadt, Germany. For later stages of operations, there are plans to have an asymmetric $\bar{p}p$ collider, with moderate proton and antiproton energies of 3.5 and 15 GeV, respectively. So far, theoretical work has focused on the Drell-Yan process. It was found that the expected spin asymmetries could be very large, possibly reaching several tens of per cents [14–16]. This can be readily understood, because for the GSI kinematics only partons with rather large momentum fractions scatter off each other, and in $\bar{p}p$ collisions the relevant lowest order (LO) process, $q\bar{q}$ annihilation, will receive large contributions from valence quarks, which are expected to carry strong polarization. This appears to make the proposed measurements at GSI particularly interesting for learning about transversity.

The theoretical framework for GSI kinematics is somewhat more involved than for RHIC, since perturbative all-order resummations of large logarithmic contributions to the partonic cross sections are particularly important. For the Drell-Yan process, these have been addressed in detail recently in [16]. In any case, information from RHIC and from GSI experiments will be complementary, due to the very different kinematics accessed, and very likely both will be needed to gain sufficient knowledge about the δf over a large range in x.

In this paper, we perform a detailed study of high-p_T single-inclusive pion production in transversely polarized pp and $\bar{p}p$ collisions. In particular, we derive the next-to-leading order (NLO) QCD corrections to the relevant partonic cross sections. In general, these are indispensable for arriving at a firmer theoretical framework for analyzing experimental data in terms of parton densi-

ties. For the calculation we employ a recently developed "projection technique" for treating the phase space integrals in the presence of the $\cos(2\Phi)$ azimuthal-angular dependence associated with transverse polarization [11].

We will apply our analytical results in phenomenological studies for pp and $\bar{p}p$ scattering at RHIC and GSI energies, respectively. Regarding the latter, to our knowledge our study is the first to propose accessing transversity via the process $\bar{p}p \to \pi X$. We hope that such measurements would be possible with the proposed PAX [12] and ASSIA [13] experiments, but this reaction should also be of great interest for the PANDA Collaboration [17]. As we shall see, the spin asymmetry for $\bar{p}p \to \pi X$ is expected to be much smaller than that for the Drell-Yan process, a drawback that may be compensated for by the much higher event rates and, therefore, the much better statistical accuracy. We will also find, however, that the size of the NLO corrections and the scale dependence are very significant at GSI energies, so that further theoretical work will be needed before one can be confident that high-p_T pion production may be a useful tool to learn about transversity. If so, combined information from Drell-Yan and from $\bar{p}p \to \pi X$ (or other produced hadrons) could be useful since the processes probe different combinations of the transversity densities.

In the next section we will very briefly review the necessary technical framework for the computation of the NLO QCD corrections. Details on the projection technique, which is a crucial tool for the calculation, can be found in Ref. [11] where it was applied to prompt-photon production. In Sec. III we will present phenomenological results for RHIC and GSI energies. We conclude in Sec. IV.

II. TECHNICAL FRAMEWORK

According to the factorization theorem [18], the fully differential, transverse-spin dependent, single-inclusive cross section for the reaction $AB \to \pi X$ for the production of a pion (or any other hadron) with transverse momentum p_T, azimuthal angle Φ with respect to the initial spin axis, and pseudorapidity η reads at NLO accuracy

$$\begin{aligned}\frac{d^3\delta\sigma}{dp_T\, d\eta\, d\Phi} &= \frac{p_T}{\pi S}\sum_{ab\to cX}\int_{1-V+VW}^{1}\frac{dz_c}{z_c^2}\int_{VW/z_c}^{1-(1-V)/z_c}\frac{dv}{v(1-v)}\int_{VW/vz_c}^{1}\frac{dw}{w}\,\delta f_a(x_a,\mu)\delta f_b(x_b,\mu)D_c^{\pi}(z_c,\mu)\\ &\times\left[\frac{d\delta\hat{\sigma}^{(0)}_{ab\to cX}(v)}{dvd\Phi}\delta(1-w)+\frac{\alpha_s(\mu)}{\pi}\,\frac{d\delta\hat{\sigma}^{(1)}_{ab\to cX}(s,v,w,\mu)}{dvdwd\Phi}\right]\ ,\end{aligned} \tag{3}$$

where the sum is over all contributing partonic channels $ab \to cX$, $AB = pp$ or $\bar{p}p$, and with hadron-level variables

$$\begin{aligned} V &\equiv 1+\frac{T}{S}\ ,\ W\equiv\frac{-U}{S+T}\ ,\ S\equiv(P_A+P_B)^2\ ,\\ T &\equiv (P_A-P_\pi)^2\ ,\ U\equiv(P_B-P_\pi)^2\ ,\end{aligned} \tag{4}$$

in obvious notation of the momenta. The corresponding partonic quantities are given by

$$\begin{aligned} v &\equiv 1+\frac{t}{s}\ ,\ w\equiv\frac{-u}{s+t}\ ,\ s\equiv(p_a+p_b)^2\ ,\\ t &\equiv (p_a-p_c)^2\ ,\ u\equiv(p_b-p_c)^2\ .\end{aligned} \tag{5}$$

Neglecting all masses, one has the relations

$$\begin{aligned} s &= x_a x_b S\ ,\ t=\frac{x_a}{z_c}T\ ,\ u=\frac{x_b}{z_c}U\ ,\\ x_a &= \frac{VW}{vwz_c}\ ,\ x_b=\frac{1-V}{(1-v)z_c}\ .\end{aligned} \tag{6}$$

The transversity densities in Eq. (3) always refer to those for a parent proton even for $AB = \bar{p}p$, i.e., we use the charge conjugation property $\delta f_a^{\bar{p}} = \delta f_{\bar{a}}^{p}$. The fact that we are observing a specific hadron in the reaction requires the introduction of additional long-distance functions in Eq. (3), the parton-to-pion fragmentation functions D_c^{π}. The $d\delta\hat{\sigma}^{(i)}_{ab\to cX}$ are the LO ($i = 0$) and NLO ($i = 1$) contributions in the cross sections for the partonic reactions $ab \to cX$. Finally, μ collectively denotes the renormalization and factorization scales, which we will always take as equal for simplicity.

We now give a few technical details of the NLO calculation. Projection on a definite polarization state for the initial partons involves the Dirac matrix γ_5. It is well known that in dimensional regularization, which we will use to regularize the ultraviolet, infrared, and collinear singularities at intermediate stages of the calculation, the treatment of γ_5 is in general a subtle issue. However, owing to the chirally odd nature of transversity, in our calculation all Dirac traces contain *two* γ_5 matrices, and, therefore, using the "HVBM scheme" [19] or a naive, totally anticommuting γ_5 in $n \neq 4$ dimensions must give the same results which is also a useful check for the correctness of the calculation.

The transverse polarization vectors of the initial hadrons give rise to a characteristic dependence of the cross section on the azimuthal angle Φ of the observed particle. In the hadronic center-of-mass system (c.m.s.) frame, taking the initial hadrons along the $\pm z$ axis and their spin vectors in $\pm x$ direction, the Φ-dependence is of the form $\cos(2\Phi)$. Integration over Φ is therefore not appropriate. Keeping Φ fixed in the NLO calculation is however very cumbersome since standard techniques developed in the literature for performing NLO phase-space integrations rely on the choice of particular reference frames different from the one specified above. In [11] we developed a general projection method that involves integration over all Φ, thereby allowing to keep the benefits of the standard phase space integration techniques. The trick, and the virtue of our method, is to project out the dependence of the matrix elements on the spin vectors in a *covariant* way, by multiplying with a covariant expression for the $\cos(2\Phi)$ term, and to then carry out the complete phase space integrals.

To be more specific, we note that because of the $\cos(2\Phi)$ dependence we have the identity

$$\frac{d^3\delta\sigma}{dp_T d\eta d\Phi} \;\equiv\; \cos(2\Phi)\int_0^{2\pi} d\Phi'\,\frac{\cos(2\Phi')}{\pi}\,\frac{d^3\delta\sigma}{dp_T d\eta d\Phi'}\;. \tag{7}$$

The $\cos(2\Phi)$ dependence actually arises through the covariant expression

$$\mathcal{F}(p_c,s_a,s_b) \;=\; \frac{s}{tu}\left[2\,(p_c\cdot s_a)\,(p_c\cdot s_b) \;+\; \frac{tu}{s}\,(s_a\cdot s_b)\right]\;, \tag{8}$$

where the s_i $(i=a,b)$ are the initial transverse spin vectors which satisfy $s_i\cdot p_a = s_i\cdot p_b = 0$ and $s_a^2 = s_b^2 = -1$. $\mathcal{F}(p_c,s_a,s_b)$ reduces to $\cos(2\Phi)$ in the hadronic c.m.s. frame. We may, therefore, use $\mathcal{F}(p_c,s_a,s_b)/\pi$ instead of the explicit $\cos(2\Phi)/\pi$ in the "projector" in the integrand of Eq. (7). For any contributing partonic channel we multiply the squared matrix element for transversely polarized initial partons, $\delta|M|^2_{ab\to cX}$, by $\mathcal{F}(p_c,s_a,s_b)/\pi$. The resulting expression may then be integrated over the full azimuthal phase space in a covariant way without producing a vanishing result, unlike the case of $\delta|M|^2$ itself; see Ref. [11] for further details. It is crucial here that the other observed ("fixed") quantities, the hadron's transverse momentum p_T and pseudorapidity η, are determined entirely by scalar products $(p_a\cdot p_c)$ and $(p_b\cdot p_c)$, independently of the spin vectors $s_{a,b}$.

Our method becomes particularly convenient for treating the $2\to 3$ scattering contributions arising at NLO where one has an additional phase space integral over the second unobserved parton in the final-state. After applying the projection method we can perform all phase space integrations by employing techniques familiar from the corresponding calculations in the unpolarized and longitudinally polarized cases [20, 21]. We note that as a non-trivial check on our calculation we have also integrated all squared matrix elements over the spin vectors *without* using any projector at all. This amounts to integrating $\cos(2\Phi)$ over all $0\le\Phi\le 2\pi$, and, as expected, the final answer is zero.

The use of dimensional regularization is straightforward in all this. Ultraviolet poles in the virtual diagrams are removed by the renormalization of the strong coupling constant. Infrared singularities cancel in the sum between virtual and real-emission diagrams. After this cancellation, only collinear poles are left. From the factorization theorem it follows that these need to be factored into the parton distribution and fragmentation functions. This is a standard procedure which we have also described in quite some detail in [11, 21]. We use the $\overline{\rm MS}$ scheme throughout.

After factorization, we arrive at the final result, the finite partonic NLO hard scattering cross sections. There are all in all five subprocesses that contribute for transverse polarization:

$$\begin{aligned} qq &\to qX, \\ q\bar{q} &\to qX, \\ q\bar{q} &\to q'X, \\ q\bar{q} &\to gX, \\ qq &\to gX\;, \end{aligned} \tag{9}$$

where at NLO in each case X denotes a one- or two-parton final state, summed over all possibilities and integrated over its phase space. The first four of these reactions are present at LO already. The corresponding LO transversity cross sections may be found in [8–10, 22]. The last subprocess appears for the first time at NLO. For each of the five subprocesses, the NLO expression for the transversely polarized cross section can be cast into the following form:

$$s\,\frac{d\delta\hat{\sigma}^{(1)}_{ab\to cX}(s,v,w,\mu)}{dvdwd\Phi} \;=\; \cos(2\Phi)\left(\frac{\alpha_s(\mu)}{\pi}\right)^2\Bigg[\left(A_0\delta(1-w)+B_0\frac{1}{(1-w)_+}+C_0\right)\ln\frac{\mu^2}{s}$$

$$+A\delta(1-w)+B\frac{1}{(1-w)_+}+C+D\left(\frac{\ln(1-w)}{1-w}\right)_+ +E\ln w+F\ln v+G\ln(1-v)$$

$$+H\ln(1-w)+I\ln(1-vw)+J\ln(1-v+vw)+K\frac{\ln w}{1-w}+L\frac{\ln\frac{1-v}{1-vw}}{1-w}+M\frac{\ln(1-v+vw)}{1-w}\Bigg], \qquad (10)$$

where the "plus"-distribution is defined in the usual way over the interval $[0,1]$. All coefficients in Eq. (10) are functions of v and w, except those multiplying the distributions $\delta(1-w)$, $1/(1-w)_+$, $[\ln(1-w)/(1-w)]_+$ which may be written as functions just of v. Terms with distributions are present only for the subprocesses that already contribute at the Born level. The coefficients are available upon request as a FORTRAN code from the authors.

III. PHENOMENOLOGICAL RESULTS

We now present some phenomenological results for single-inclusive pion production in transversely polarized pp collisions at RHIC ($\sqrt{S}=200$ and 500 GeV) and asymmetric $\bar{p}p$ collisions at the planned GSI-FAIR facility with proton and antiproton energies of 3.5 GeV and 15 GeV, respectively.

Since nothing is known experimentally about transversity so far, we need to model the δf for our study. Guidance is provided by the Soffer inequality [23]

$$2\,|\delta q(x)| \leq q(x)+\Delta q(x) \qquad (11)$$

which gives bounds for each δf. As in [10, 11] we utilize this inequality by saturating the bound at some low input scale $\mu_0 \simeq 0.6$ GeV, choosing all signs to be positive, and using the NLO (LO) GRV [24] and GRSV ("standard scenario") [25] densities $q(x,\mu_0)$ and $\Delta q(x,\mu_0)$, respectively. For $\mu>\mu_0$ the transversity densities $\delta f(x,\mu)$ are then obtained by evolving them at LO or NLO. We refer the reader to [7, 10] for more details on our model distributions. We note that we will always perform the NLO (LO) calculations using NLO (LO) parton distribution functions and the two-loop (one-loop) expression for α_s. We use the pion fragmentation functions of Ref. [26] which has both a LO and an NLO set. They provide a very good description of the recent RHIC data on unpolarized neutral-pion production [27].

Figure 1 shows our estimates for the transversely polarized single-inclusive pion production cross sections at LO and NLO for the two different c.m.s. energies at RHIC. We have integrated over the range $|\eta| \leq 0.38$ in pseudorapidity, appropriate for measurements with the PHENIX detector. Since only half of the pion's azimuthal angle is covered, we integrate over the two quadrants $-\pi/4<\Phi<\pi/4$ and $3\pi/4<\Phi<5\pi/4$, which gives $\left(\int_{-\pi/4}^{\pi/4}+\int_{3\pi/4}^{5\pi/4}\right)\cos(2\Phi)d\Phi = 2$. We have also varied simultaneously the factorization/renormalization scales μ in Eq. (3) within $p_T \leq \mu \leq 4p_T$; a significant decrease of scale dependence is observed when going from LO to NLO.

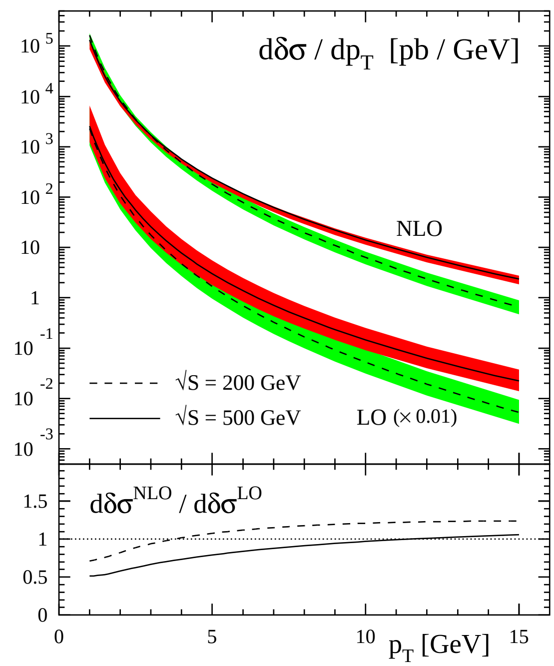

FIG. 1: Transversely polarized single-inclusive neutral-pion production cross sections in LO and NLO for $\sqrt{S}=200$ and 500 GeV collisions at RHIC. The LO results have been scaled by a factor of 0.01. The shaded bands represent the changes if the scale μ is varied in the range $p_T \leq \mu \leq 4p_T$. The lower panel shows the ratios of the NLO and LO results for both c.m.s. energies.

The lower part of the Figure 1 displays the so-called "K-factor", defined as usual as the ratio of the NLO to the LO cross section, for the scale choice $\mu=2p_T$. Except for small p_T, where the NLO corrections lead to a significant reduction of the cross section, the K-factor turns out to be rather moderate and close to unity. It is known that the K-factor for the unpolarized cross section is significantly larger than one at RHIC energies, see, e.g., Fig. 4 in Ref. [21] for $\sqrt{S}=200$ GeV, mostly because of large corrections found for gluon-initiated partonic channels. Therefore, one expects that the double-spin asymmetry A_{TT} at RHIC will decrease when going from LO to NLO. Indeed, as Fig. 2 shows, this is the case. Here we used the CTEQ6M (CTEQ6L1) [28] set of unpolarized parton distributions to calculate the corresponding NLO (LO) unpolarized cross section. We have chosen the scale $\mu=p_T$ which leads to the largest cross sections in Fig. 1. We also indicate in Fig. 2 an estimate of the statistical

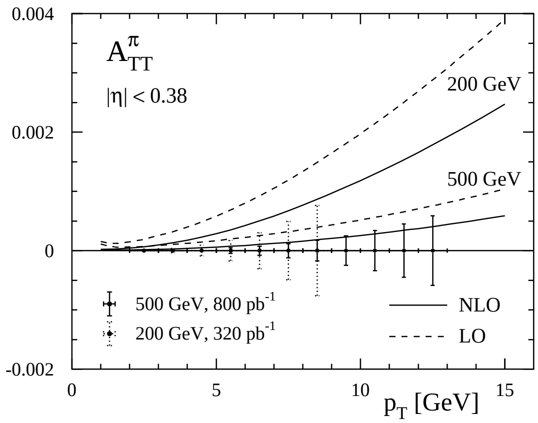

FIG. 2: Upper bounds for the double-transverse spin asymmetry $A_{\rm TT}$ corresponding to Fig. 1. The "error bars" indicate the statistical accuracy that might be achievable at RHIC (see text).

accuracy that might be achievable at RHIC, based on

$$\delta A_{\rm TT} \simeq \frac{1}{P_A P_B \sqrt{\mathcal{L}\,\sigma_{\rm bin}}} \ , \tag{12}$$

with beam polarizations $P_{A,B}$ of 70%, and an integrated luminosity $\mathcal{L}$ of 320 and $800\,{\rm pb}^{-1}$ for c.m.s. energies of $\sqrt{S} = 200$ and 500 GeV, respectively. $\sigma_{\rm bin}$ denotes the unpolarized cross section integrated over the p_T-bin for which the error is to be determined. Clearly, the statistics would be sufficient to measure even asymmetries as small as the ones shown in Fig. 2. However, it is likely that the systematic error on spin asymmetries at RHIC will not be much smaller than 10^{-3}, in which case it would appear to be very difficult to access transversity from $A_{\rm TT}$ for single-inclusive pion production. We stress again that the results shown in Fig. 2 are upper bounds, at least within the GRV/GRSV framework with its low input scale for the evolution. If the bound in Eq. (11) turns out to be not saturated at that scale the asymmetries would be even smaller. On the other hand, if we used transversity densities that saturate Eq. (11) at a higher scale, say $\mu_0 \simeq 1\,$GeV, the results for $A_{\rm TT}$ would be somewhat larger. In any case the measurement is very challenging at RHIC.

We now turn to transversely polarized $\bar{p}p$ collisions with $\sqrt{S} = 14.5$ GeV at the planned GSI-FAIR facility. We first note that for this rather moderate c.m.s. energy the pion transverse momentum can at most reach 7.25 GeV, at mid rapidity. In our study we integrate over $-1 < \eta_{\rm lab} < 2.5$, where $\eta_{\rm lab}$ is the pseudorapidity of the pion in the laboratory frame. We count positive rapidity in the forward direction of the antiproton. For the asymmetric collider option we consider here, $\eta_{\rm lab}$ is related to the c.m.s. pseudorapidity η via

$$\eta_{\rm lab} = \eta + \frac{1}{2} \ln \frac{E_{\bar{p}}}{E_p} \ , \tag{13}$$

where $E_{\bar{p}}$, E_p are the antiproton and proton energies. The rapidity interval we use is roughly symmetric in c.m.s. pseudorapidities, $|\eta| \lesssim 1.75$.

Figure 3 shows our results for the unpolarized (left) and transversely polarized (right) cross sections at NLO and LO, as functions of p_T. For the calculation in the unpolarized case we have chosen the GRV [24] parton distributions. This choice is motivated by our ansatz for the transversity distributions, for which we had also used the GRV densities when saturating the Soffer inequality, Eq. (11). Unlike at RHIC energies, at $\sqrt{S} = 14.5$ GeV and p_T of several GeV, rather large momentum fractions $x_{a,b}$ of the partons are probed in Eq. (3), where the polarized and unpolarized parton densities for a given parton type are expected to become similar [29]. It then appears most sensible to use the same parton distributions in the unpolarized case that we used when modeling the transversity densities. In this way we avoid any artificial effects in the NLO corrections and $A_{\rm TT}$ induced by a mismatch in the $x \to 1$ behavior of the parton densities used in the calculation.

The shaded bands in the upper panels of Fig. 3 again indicate the uncertainties due to scale variation in the range $p_T \leq \mu \leq 4p_T$. One can see that for both, the unpolarized and the polarized cross sections, the scale dependence does not really improve from LO to NLO. This is a characteristic feature in low-order perturbative calculations of cross sections for lower fixed-target energies, suggesting that corrections beyond NLO are still very significant. Indeed, it was recently shown [30] that for inclusive-hadron production in the fixed-target regime certain double-logarithmic corrections to the partonic cross sections are important at each order of perturbation theory, and need to be resummed to all orders to achieve an adequate theoretical description. Such a resummation will be required in particular in the case we are considering here and would be very desirable for the future, along with a study of power corrections. We emphasize that when the proposed measurements of $A_{\rm TT}$ will be performed, it will be crucial to have precise measurements also of the unpolarized cross section, in order to test the theoretical framework. Only if the theory is sufficiently understood will data on $A_{\rm TT}$ become useful for determining transversity. Similar comparisons of data [27] and theoretical calculations for the unpolarized neutral-pion cross section at RHIC have shown an excellent agreement even down to fairly low pion transverse momenta, which has indeed provided much confidence that the calculations based on partonic hard-scattering are adequate, so that spin asymmetries measured at RHIC determine the spin-dependent parton distributions of the proton.

The lower parts of Fig. 3 display the corresponding K-factors at scale $\mu = 2p_T$. We note that these decrease as p_T increases, which is related entirely to the different behavior of the LO and NLO parton distributions at large x. Had we chosen the same parton distributions at LO and NLO, the K-factors would actually slightly *increase* with p_T, as a result of the large double-logarithmic cor-

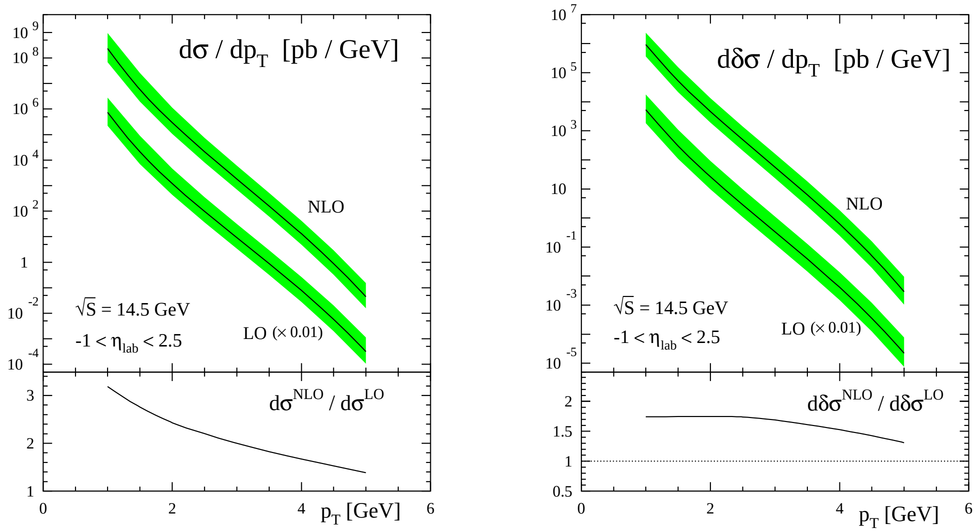

FIG. 3: Unpolarized (left) and transversely polarized (right) single-inclusive neutral-pion production cross sections at LO and NLO at the GSI. The LO results have been scaled by a factor of 0.01. The shaded bands represent the theoretical uncertainty if the factorization/renormalization scale μ is varied in the range $p_T \leq \mu \leq 4p_T$. The lower panel shows the ratios of the NLO and LO results in each case, using $\mu = 2p_T$.

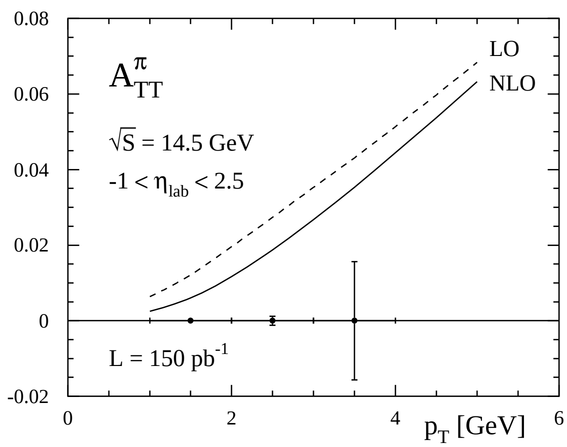

FIG. 4: Upper bounds for the transverse double-spin asymmetry $A_{\rm TT}$ for single-inclusive neutral-pion production in LO and NLO at GSI-FAIR. The "error bars" indicate the expected statistical accuracy for bins in p_T (see text).

rections mentioned above, which first arise at NLO and are known to enhance the cross section.

Figure 4 shows upper bounds–again within the GRV/GRSV framework–for the double-spin asymmetry $A_{\rm TT}$ for the GSI-FAIR facility. The scale μ is again set to p_T. We also give expectations for the statistical errors that may be achievable in experiment. We have calculated these using Eq. (12), assuming an integrated luminosity of $\mathcal{L} = 150\,\text{pb}^{-1}$, and beam polarizations of 30% and 50% for the antiprotons and protons, respectively.

IV. CONCLUSIONS

We have presented in this paper the complete NLO QCD corrections for the partonic hard-scattering cross sections relevant for the double-spin asymmetry $A_{\rm TT}$ for single-inclusive high-p_T pion production in collisions of transversely polarized hadrons. This asymmetry could be a tool to determine the transversity distributions of the nucleon. Our calculation is based on a largely analytical evaluation of the NLO partonic cross sections, and we have used a projection technique for treating the characteristic azimuthal-angle dependence introduced by the transverse spin vectors.

In our phenomenological studies we found that the spin asymmetry $A_{\rm TT}$ is expected to be very small in pp collisions at RHIC and even decreases when going from LO to NLO, due to a larger K-factor in the unpolarized case. We have also studied $A_{\rm TT}$ for possibly forthcoming transversely polarized $\bar{p}p$ collisions in an asymmetric collider mode at the GSI-FAIR facility. Here, the spin asymmetry may be much larger, but it will be crucial in the future to investigate the effects of all-order resummations of large Sudakov logarithms. Detailed measurements of the unpolarized cross sections will be essential for testing the applicability of the theoretical framework at the moderate c.m.s. energies available at GSI-FAIR.

Acknowledgments

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